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STRESS CORROSION CRACKING OF SEVERAL HIGH STRENGTH FERROUS AND NICKEL ALLOYS

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16. Abstract

The stress corrosion cracking resistance of several high strength ferrous and nickel base alloys has been determined in a sodium chloride solution. Results indicate that under these test conditions Multiphase MP35N, Unitemp L605, Inconel 718, Carpenter 20Cb and 20Cb-3 are highly resistant to stress corrosion cracking. AISI 410 and 431 stainless steels, 18 Ni maraging steel (250 grade) and AISI 4130 steel are susceptible to stress corrosion cracking under some conditions.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

STRESS CORROSION CRACKING OF SEVERAL HIGH STRENGTH FERROUS AND NICKEL ALLOYS

INTRODUCTION

The rapid development of high strength ferrous and nickel base alloys has played an important role in valves, fasteners, turbine nozzles and turbopumps employed in jet engines, missiles, supersonic aircraft, and space vehicles[1]. Because of the fast development and the limited amount of data available on such alloys, a widening gap has developed in the technical knowledge of the stress corrosion characteristics of many of these alloys. Experience has shown that alloys with high tensile properties have a high affinity for stress corrosion cracking. The subject work was initiated to determine the stress corrosion susceptibility of several of these high strength alloys. The alloys evaluated were types AISI 410 and 431 stainless steel. Multiphase MP35N, Carpenter 20Cb and 20Cb-3, Inconel 718, Unitemp L-605, 18 Ni maraging steel (250 grade) and type 4130 steel. The alloys that are hardenable only by cold work (Carpenter 20Cb and 20Cb-3, and Unitemp L-605) were evaluated in the annealed condition, and the remaining alloys were evaluated in their commonly used heat treatments (See Table II).

The need for ultra-high strength alloys with high resistance to stress corrosion cracking and with good resistance to general surface corrosion is ever present. Preliminary data on Multiphase MP35N, a quaternary cobalt, nickel, chromium and molybdenum alloy recently developed by I. E. du Pont de Nemours, seems to meet these requirements. The strength of this metal is attained by transforming the face-center-cubic material to a hexagonal-close packed phase[2]. Inconel 718 (nickel base alloy), an intermediate strength alloy, possesses good general corrosion and SCC resistant qualities in the aged condition, particularly to moist chlorides[3], at room temperature. The L-605 (cobalt base alloy) and Carpenter 20Cb and 20Cb-3, (nickel-chromium) are medium and low strength alloys with good SCC resistance. These alloys are usually used in the annealed condition, but additional strength can be attained through cold working.

AISI 410, a low carbon, chromium stainless steel has intermediate strength up to 1370 MN/m^2 (200 ksi) when heat treated. Under certain tempering temperatures it is reported to be highly resistant to stress corrosion cracking, while in other tempers it is susceptible to stress corrosion cracking[4-5]. This alloy (or any of the 12 percent chromium steels) develops a high degree of resistance to atmospheric corrosion because of its ability to form a tightly adherent oxide film which protects its surface from further attack. AISI 4130 steel is very susceptible to general surface type corrosion and normally required surface treatment for most applications. The 4130 steel used in the evaluation was cadmium plated.

EXPERIMENTAL PROCEDURES

Three types of specimens were used to test the stress corrosion resistance of these alloys in at least two directions of grain orientation. Flat tensile type specimens were used for testing sheet material and were loaded by constant deflection. Round tensile type specimens stressed in uniaxial tension were used for testing the longitudinal and long transverse direction of 0.635 cm (0.250 inch) thick plate and the longitudinal direction of all bar stock, and the transverse directionof 5.08 cm (2 inches) or greater diameter bar stock. C-rings, utilizing the constant deflection method, were used for the transverse direction of bar stock of less than 5.08 cm (2 inches) in diameter.

All heat treated round and flat tensile specimens were wet-grit blased with fast-cut (quartz) #325 abrasive to remove surface oxides. All specimens were washed in cold running water and given an alcohol rinse to facilitate drying. Specimens fabricated from type 4130 steel were cadmium plated per QQ-P-416, Class 2, Type II, baked 24 hours at 450°K (350 °F) to prevent hydrogen embrittlement and then given a chromate treatment.

The desired stress levels (50 to 100 percent of the directional yield strength) were calculated from measured mechanical properties. The specimens were deflected or strained the desired amount, wiped clean with acetone, and exposed in the alternate immersion tester and salt spray cabinet until failure occurred, or until the test was terminated at the end of approximately six months. Unstressed tensile specimens were exposed under identical conditions to determine the loss of properties from general surface corrosion. A detailed description of the test specimens, formulas for calculating deflection and strain, and method of testing and loading are given in Ref. 6. The tests were conducted in a ferris wheel type alternate immersion tester (Figure 1) containing a 3.5 percent solution (deionized water) of sodium chloride having a pH of 6.8 to 7.2 The exposure cycle was 10 minutes in solution, followed by 50 minutes of drying above the solution, each hour. The type 431 stainless steel was also tested in a 5 percent salt spray cabinet in accordance with ASTM B117-64.

RESULTS AND DISCUSSION

The compositions of the alloys evaluated are given in Table I. Typical analyses are given for some materials where the specific compositions were not determined. The mechanical properties and heat treatments used are shown in Tables II and III. The complete stress corrosion results are listed in Table IV.

The results indicate that 20Cb and 20Cb-3 stainless steel, Inconel 718, L-605, and Multiphase MP35N are highly resistant to stress corrosion cracking and to general surface corrosion in a 3.5 percent sodium chloride solution in all conditions tested. Test results also indicate that type 410 stainless, 18 Ni maraging steel (250 grade) and type 4130 steel are susceptible to stress corrosion cracking in a 3.5 percent salt water solution. Type 431 stainless steel cracked in the salt spray environment, but not in the alternate immersion tester. In most of the alloys tested the final mechanical properties of the unstressed and stressed specimens resulted in negligible loss in tensile strength after 180 days exposure in the alternate immersion tester, with the exception of alloy 410 stainless steel, 18 Ni maraging steel (250 grade) and alloy 4130 steel specimens as shown in Table IV.

AISI 410 Stainless Steel. - Both 0.127 cm (0.050 inch) sheet and 0.635 cm (0.250 inch) plate were evaluated for stress corrosion cracking in four heat treated conditions (A, B, C, D, as described in Table III). Although both sheet and plate material contained inclusions, no stress corrosion failure occurred in the sheet materials, but failures did occur in the plate.

Condition A material with low mechanical properties and find grain with carbide precipitation at the grain boundaries (Figure 2) exhibited severe general surface corrosion with numerous deep pits. Tensile tests performed on the stress corrosion specimens after exposure indicated large and erratic loses in tensile strength. The only failure in the group, a transverse specimen stressed to 100 percent of the yield strength, is believed to have resulted from overload due to large deep pits.

Condition B is the most generally used heat treatment for type 410 stainless steel and gives the material medium mechanical properties with a fine grain structure with no carbide precipitation at the grain boundaries (Figure 3). The general surface corrosion of material in Condition B is much less than in Condition A. Condition B material was found to be susceptible to stress corrosion cracking (SCC) in the transverse and longitudinal grain directions at the 100 percent stress level. The lack of general surface corrosion on the control specimens is indicated by the negligible loss in tensile strength.

The only difference in Condition C and D is the autenitizing temperature, with C being within specification and D being slightly above specification requirements. Both conditions produced the same medium mechanical properties and large grain (Figures 4 and 5). General surface corrosion was relatively light, as in Condition B. Both conditions were very susceptible to SCC at the 75 and 100 percent stress level in the transverse and longitudinal grain directions.

AISI 431 Stainless Steel. - No stress corrosion failures occurred in type 431 stainless steel exposed in the alternate immersion tester in either the longitudinal or transverse direction, but transverse specimens exposed in the salt spray cabinet failed in both the annealed and aged conditions when loaded at 100 percent of the yield strength. The two failures cannot be attributed entirely to SCC because of inclusions in the metal near the fractures. The general surface corrosion on these specimens was essentially nil in both environments with the exception of areas adjacent to the inclusions and on the fractured surface.

18 Ni Maraging Steel (250 Grade). - Alloy 18 Ni maraging steel (250 grade) was resistant to SCC failures in the normally aged and overaged conditions, but was very susceptible to SCC at all stress levels tested in the underaged and resolution heat treated and aged condition. All conditions are listed in Table III.

One specimen failed in the normally aged material in the transverse direction stressed to 100 percent of the yield strength, 1865 MN/m^2 (256 ksi). Metallographic examination revealed the fracture to be that of pit-type corrosion (Figure 6), which reduced the metal thickness, resulting in overload and ultimate specimen failure. Specimens in all five heat treated conditions were susceptible to general surface corrosion and pitting. The greatest amount of corrosion occurred on specimens heat treated to Conditions A and E. The others had the same type of corrosion but to a much lesser degree.

AISI 4130 Steel. - Of the two strength levels evaluated in both sheet and bar, failures occurred only to the sheet material stressed to 100 percent of the directional yield strength at 1379 MN/m^2 (200 ksi) strength level. Figures 7A and B show sheet material before and after exposure, with the exposed specimens showing the attack and breakdown of the cadmium plate. Photomicrographs (Figure 8) obtained from broken specimens show intergranular attack, characteristic of stress corrosion cracking. The time to failure ranged from 26 to 144 days. Although alloy 4130 steel is very susceptible to surface and stress corrosion, it can be protected with many types of coatings as in this study, where the cadmium plate was not destroyed, the final mechanical properties were good; where the coatings was destroyed, failures occurred.

CONCLUSIONS AND RECOMMENDATIONS

The results obtained from this study indicate the following:

1. Multiphase MP35N, Carpenter 20Cb and 20Cb-3, Inconel 718, and Unitemp L-605 are highly resistant to stress corrosion in a chloride environment at room temperature .

2. Longitudinal and transverse specimens made from 431 stainless steel bar in the annealed and aged conditions were resistant to stress corrosion cracking in the alternate immersion bath, but failures occurred to transverse specimens in both conditions exposed in the salt spray. However, these failures could be attributed to the inclusions found in the metal near the fractured surface.

3. (a) In three of the four heat treated conditions investigated, 410 stainless steel was very susceptible to SCC. If the alloy is austenitized at 1242°K (1775°F) and tempered 3 hours at 867°K (1100°F), yielding the lowest mechanical properties, it is resistant to SCC in the chloride environment.

(b) Alloy 410 stainless steel austenitized at 1283°K (1850°F) and aged 3 hours at 867°K (1100°F), will be evaluated to compare mechanical properties and stress corrosion resistance with alloy 410 austenitized at 1242°K (1775°F).

4. (a) The 18 Ni maraging steel (250 grade) was resistant to SCC in the aged conditions of 756, 783, 811 °K (900, 950, 1000°F) in a chloride environment, but the aged condition of 725°K (850°F) was susceptible to SCC. This alloy was also susceptible when resolution heat treated for one hour at 1144°K (1600°F), and aged for 3 hours at 756°K (900°F).

(b) 18 Ni maraging steel (250 grade) will be austenitized for a longer period of time to create large grains and then aged at 756, 783, 811°K (900, 950, 1000°F). The properties of this material will then be compared with those previously obtained to see if the performance has improved or deteriorated.

(c) Another intended area of investigation for maraging steel is the possible retention of austenite which transforms to untempered martensite at some latter time. This untempered martensite formed from retained austenite results in additional straining of the material causing problems which directly effect stress corrosion properties.

5. (a) Cadmium plated 4130 steel with chromate conversion treatment was not susceptible to SCC at the 1069 MN/m^2 (160 ksi) strength level, but was susceptible at the 1110 MN/m^2 (200 ksi) strength level in a chloride environment.

(b) The 4130 stainless steel alloy is also very susceptible to general surface corrosion. Not only should this alloy have some protective plating but it should also have a good coat of paint, if possible, to further aid in this protection against corrosion of all types.

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APPENDIX A

Conversion of U. S. Customary Units to SI Units

The International Systems of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures in 1960. Conversion factors for the units used herein are given in the following table:

Physical Quantity	U. S. Customary Unit	Conversion Factors (a)	SI Units (b)
Length	In.	0.0254	meter (m)
Stress	psi	6895	newton/meter^2 (N/M^2)
Temperature	°F	5/9 (°F + 460)	Kelvin (K)

(a) Multiply value given in U. S. Customary Units by conversion factor to obtain equivalent value in SI Unit

(b) Prefixes to indicate multiple units as follows:

PREFIX	MULTIPLE
centi (c)	10^{-2}
mega (M)	10^{6}

TABLE I

CHEMICAL ANALYSIS OF METAL ALLOYS

Alloy	Source and Heat No.		Form	Composition, Weight % C	MN	P	S	Si	Cr	Ni	Mo	Cu	Cb + Ta	Other	Fe
AISI 410 CRES	Republic	3330239	Plate	0.14	0.53	.020	.009	0.39	12.25	0.20	0.06	0.19	-	(2)	Bal.
	Unknown		Sheet (1)	0.15	1.00	-	.030	1.00	12.50	-	-	-	-	-	Bal.
AISI 431 CRES	Armco	36571	Bar	0.14	0.48	.024	.024	0.44	15.68	2.36	-	-	-	(3)	Bal.
18 Ni Mar. Stl. (250 Gd)	Van-Pac.	09821	Plate	.015	0.08	.004	.007	0.05	-	18.10	4.78	-	-	(4)	Bal.
Inconel 718	Cameron	50284	Plate	.050	0.11	.006	.004	0.20	18.50	52.42	3.12	0.04	5.46	(5)	Bal.
	Unknown		Sheet (1)	.100	0.40	0.15	.015	0.45	19.00	52.00	3.05	0.30	5.15	(6)	Bal.
20Cb	Carpenter		Sheet (1)	0.07	2.00	-	-	1.00	20.00	26.50	2.50	3.50	1.00	-	Bal.
	Carpenter		Bar (1)	0.07	2.00	-	-	1.00	20.00	26.50	2.50	3.50	1.00	-	Bal.
20Cb-3	Carpenter	30776	Sheet	0.04	0.38	.016	.004	0.38	19.64	33.08	2.25	3.29	0.82	-	Bal.
	Carpenter	24503	Bar	0.05	0.34	.014	.005	0.37	19.84	33.44	2.25	3.34	0.86	-	Bal.
	Carpenter	26288	Bar	0.05	0.21	.016	.006	0.41	19.95	33.93	2.27	3.34	0.83	-	Bal.
L-605	Univ. Cyc.	B19341	Sheet	0.07	1.48	.013	.111	0.21	19.65	10.36	-	-	-	(7)	2.50
	Univ. Cyc.	B19252	Bar	0.07	1.50	.009	.111	0.18	19.90	10.35	-	-	-	(8)	2.32
Multiphase	Latrobe	51010	Bar	.014	.003	.003	.003	0.06	19.57	35.25	9.86	-	-	(9)	-
AISI 4130 Steel	Unknown		Sheet (1)	0.50	0.50	.040	.040	0.27	1.00	-	0.20	-	-		Bal.
	Unknown		Bar (1)	0.50	0.50	.040	.040	0.27	1.00	-	0.20	-	-		Bal.

Notes: (1) Typical Analysis
(2) 0.03 Al; 0.025 N_2; 0.018 Sn
(3) 0.059 N_2
(4) 0.05 Al; 0.37 Ti; 7.52 Co; 0.05 Ca; 0.013 Zr
(5) 0.60 Al; 0.85 Ti; 0.10 Co
(6) 0.60 Al; 1.05 Ti
(7) 14.43 W; Balance Co
(8) 14.52 W; Balance Co
(9) 34.79 Co.

TABLE II

MECHANICAL PROPERTIES OF VARIOUS HIGH STRENGTH FERROUS AND NICKEL BASE ALLOYS

Alloy	Thickness cm (in)	Heat Treatment*	Grain Direction	Tensile Str. MN/m^2 (ksi)	Yield Str. MN/m^2 (ksi)	% Elongation
410 CRES	0.635 (0.25)	A	Trans.	903 (131)	779 (113)	18.0
			Long.	910 (132)	779 (113)	21.0
	0.127 (0.050)	A	Trans.	869 (126)	765 (111)	10.8
			Long.	869 (126)	765 (111)	11.2
	0.635 (0.25)	B	Trans.	1338 (194)	1034 (150)	13.0
			Long.	1365 (198)	1055 (153)	18.0
	0.127 (0.050)	B	Trans.	1276 (185)	1014 (147)	8.5
			Long.	1269 (184)	1014 (147)	9.0
	0.635 (0.25)	C	Trans.	1427 (207)	986 (143)	17.0
			Long.	1420 (206)	1014 (147)	17.7
	0.127 (0.050)	C	Trans.	1289 (187)	952 (138)	9.7
			Long.	1269 (184)	952 (138)	8.8
	0.635 (0.25)	D	Long.	1420 (206)	1000 (145)	17.0
	0.127 (0.050)	D	Trans.	1282 (186)	952 (138)	10.0
			Long.	1276 (185)	938 (136)	9.5
431 CRES	2.54 (1.0)	A	Long.	862 (125)	800 (116)	21.5
	Dia. Bar	B	Long.	1351 (196)	952 (138)	11.0
18 Ni Maraging Steel - 250 Grade	0.635 (0.25)	A	Trans.	1669 (242)	1641 (238)	12.7
			Long.	1717 (249)	1675 (243)	11.7
		B	Trans.	1779 (258)	1765 (256)	10.0
			Long.	1738 (252)	1717 (249)	12.3
		C	Trans.	1793 (260)	1779 (258)	10.0
			Long.	1869 (271)	1848 (268)	10.0
		D	Trans.	1696 (246)	1669 (242)	12.0
			Long.	1772 (257)	1744 (253)	12.0
		E.	Trans.	1538 (223)	1476 (214)	12.7
			Long.	1559 (226)	1469 (213)	12.3
Inconel 718	0.623 (0.25)	*	Trans.	1338 (194)	1145 (166)	17.0
			Long.	1317 (191)	1124 (163)	12.0
	0.033 (0.013)		Trans.	1365 (198)	1117 (162)	19.5
			Long.	1386 (201)	1124 (163)	20.5
Carpenter 20 Cb	7.62 (3.0)	*	Trans.	627 (91)	331 (48)	43.0
	Dia. Bar		Long.	621 (90)	379 (55)	44.0
	0.160 (0.063)		Trans.	703 (102)	407 (59(	36.7
			Long.	703 (102)	393 (57)	35.0
Carpenter 20 Cb-3	5.08 (2.0)	*	Trans.	621 (90)	317 (46)	48.0
			Long.	641 (93)	352 (51)	36.7
	0.160 (0.063)		Trans.	703 (102)	407 (59)	36.7
			Long.	703 (102)	393 (57)	35.0
L605	2.54 (1.0)	*	Long.	938 (136)	455 (66)	46.0
	Dia. Bar					
	0.160 (0.063)		Trans.	945 (137)	476 (69)	48.0
			Long.	965 (140)	496 (72)	46.2

TABLE II (Continued)

MECHANICAL PROPERTIES OF VARIOUS HIGH STRENGTH FERROUS AND NICKEL BASE ALLOYS

Alloy	Thickness cm (in)	Heat Treatment	Grain Direction	Tensile Str. MN/m^2 (ksi)	Yield Str. MN/m^2 (ksi)	% Elongation
Multiphase MP-35N	2.54 (1.0) Dia. Bar	*	Long.	1931 (280)	1841 (267)	11.0
4130 Steel	0.152 (0.060)	A	Trans.	1089 (158)	979 (142)	6.0
			Long.	1083 (157)	1014 (147)	5.3
	6.35 (2.5) Dia. Bar	A	Trans.	1131 (164)	1069 (155)	6.0
			Long.	1138 (165)	1062 (154)	16.0
	0.152 (0.060)	B	Trans.	1365 (198)	1179 (171)	5.2
			Long.	1331 (193)	1179 (171)	5.0
	6.35 (2.5) Dia. Bar	B	Trans.	1262 (183)	1110 (161)	6.0
			Long.	1234 (179)	1020 (148)	11.7

* See Table IV for Heat Treatments

TABLE III

HEAT TREATMENTS

AISI 410 CRES

Condition A - Austenitized at 1242°K (1775°F) for 40 minutes (1) at temperature in vacuum furnace, argon cooled to room temperature and immediately tempered at 867°K (1100°F) for three hours in vacuum furnace (2).

Condition B - Austenitized at 1242°K (1775°F) for 40 minutes (1) at temperature in vacuum furnace, argon cooled to room temperature and immediately tempered at 533°K (500°F) for three hours in air furnace (2).

Condition C - Austenitized at 1283°K (1850°F) for 40 minutes (1) at temperature in vacuum furnace, argon cooled to room temperature and immediately tempered at 478°K (400°F) for three hours in air furnace, air cooled and retempered at 478°K (400°F) for three hours in air furnace (2).

Condition D - Austenitized at 1311°K (1900°F) for 40 minutes (1) at temperature in vacuum furnace, argon cooled to room temperature and immediately tempered at 478°K (400°F) for three hours in air furnace, air cooled and retempered at 478°K (400°F) for 3 hours in air furnace (2).

AISI 431 CRES

Condition A - Received in the hot rolled, annealed condition A per QQ-S-763C by supplier (Armco Steel Corporation).

Condition B - Hardened at 1297°K (1875°F) for 0.5 hour, oil quenched, cooled to room temperature in water, cooled to 200°K (-100°F) for two hours, tempered at 561 °K (550°F) for two hours and air cooled - cooled to 200°K (-100°F) for 2 hours, tempered at 561°K (550°F) for 2 hours air cooled (2).

AISI 18 Ni Maraging Steel (250 Grade) (Material received in the solution annealed condition)

Condition A - Aged three hours at 727°K (850°F) (2)

Condition B - Aged three hours at 756°K (900°F) (2)

Condition C - Aged three hours at 783°K (950°F) (2)

Condition D - Aged three hours at 811°K (1000°F) (2)

Condition E - Resolution heat treated for one hour at 1144°K (1600°F), argon cooled to room temperature and aged three hours at 756°K (900°F) (2).

Inconel 718 (Material Received in the Solution annealed condition)

Aged ten hours at 1033°K (1400°F), furnace reset for 922°K (1200°F) and aged for total aging time of 20 hours (2).

Carpenter Custom 20 Cb

Material tested as received in cold rolled annealed condition

Carpenter Custom 20 Cb-3

Material tested as received in cold rolled annealed condition

TABLE III (Continued)

HEAT TREATMENTS

L-605

Material tested as received - solution treated at 1506°K (2250°F).

Multiphase MP-35N

Annealed 1325°K (1925°F) for one hour, air cooled, cold drawn 50-60 percent.
Aged at 922°K (1200°F) for 4 hours and air cooled.

AISI 4130 Steel

Condition A - Treated per Mil-H-6875D to 160 ksi level (2)

Condition B - Treated per Mil-H-6875D to 200 ksi level (2)

Notes

(1) Time measured after furnace reaches minimum temperature range

(2) Aged by user

TABLE IV

STRESS CORROSION CRACKING OF VARIOUS HIGH STRENGTH FERROUS AND NICKEL ALLOYS

Alloy	Thickness cm (in)	Heat Treatment*	Direction Of Stress	Applied Stress MN/m^2 (ksi)	% of Y.S.	Failure Ratio	Days to Failure
AISI 410 CRES	0.635 (0.25)	A	Trans.	586 (85)	75	0/3	-
				779 (113)	100	1/3	178
		A	Long.	586 (85)	75	0/3	-
				779 (113)	100	0/3	-
	0.127 (0.050)	A	Trans.	586 (85)	75	0/3	-
				779 (113)	100	0/3	-
		A	Long.	586 (85)	75	0/3	-
				779 (113)	100	0/3	-
	0.635 (0.25)	B	Trans.	779 (113)	75	0/3	-
				1034 (150)	100	3/3	61, 96, 104
		B	Long.	793 (115)	75	0/3	-
				1055 (153)	100	2/3	85, 125
	0.127 (0.050)	B	Trans.	758 (110)	75	0/3	-
				1014 (147)	100	0/3	-
		B	Long.	758 (110)	75	0/3	-
				1014 (147)	100	0/3	-
	0.635 (0.25)	C	Trans.	738 (107)	75	3/3	26, 29, 40
				986 (143)	100	3/3	9, 12, 16
		C	Long.	758 (110)	75	3/3	29, 40, 54
				1014 (147)	100	2/3	19, 20
	0.127 (0.050)	C	Trans.	717 (104)	75	0/3	-
				952 (138)	100	0/3	-
		C	Long.	717 (104)	75	0/3	-
				952 (138)	100	0/3	-
	0.635 (0.25)	D	Long.	1007 (145)	100	2/2	3, 12
	0.127 (0.050)	D	Trans.	717 (104)	75	0/3	-
				952 (138)	100	0/3	-
		D	Long.	702 (102)	75	0/3	-
				938 (136)	100	0/3	-
AISI 431 CRES	0.254 (1.0) Dia. Bar	A	Long.	600 (87)	75	0/4	-
				800 (116)	100	0/4	-
		A	Trans. (2) C-Rings	400 (58)	50	0/8 (1)	-
				600 (87)	75	0/4	-
				800 (116)	100	1/8 (1)	57
		B	Long.	717 (104)	75	0/4	-
				952 (138)	100	0/4	-
		B	Trans. (2) C-Rings	462 (67)	50	0/8 (1)	-
				717 (104)	75	0/4	-
				952 (138)	100	1/8 (1)	65

TABLE IV (Continued)

STRESS CORROSION CRACKING OF VARIOUS HIGH STRENGTH FERROUS AND NICKEL ALLOYS

Alloy	Thickness cm (in)	Heat Treatment*	Direction Of Stress	Applied Stress MN/m^2 (ksi)	Applied Stress % of Y.S.	Failure Ratio	Days to Failure
18 Ni Marag' ıg Steel (250 ᴄ_ade)	0.635 (0.25)	A	Trans.	1234 (179)	75	2/3	103, 132
				1641 (238)	100	3/3	71, 75, 75
		A	Long.	1255 (182)	75	3/3	57, 75, 180
				1675 (243)	100	3/3	31, 43, 52
		B	Trans.	1324 (192)	75	0/3	-
				1765 (256)	100	1/3	169
		B	Long.	1289 (187)	75	0/3	-
				1717 (249)	100	0/3	-
		C	Trans.	1324 (192)	75	0/3	-
				1779 (258)	100	0/3	-
		C	Long.	1386 (201)	75	0/3	-
				1848 (268)	100	0/3	-
		D	Trans.	1255 (182)	75	0/3	-
				1669 (242)	100	0/3	-
		D	Long.	1310 (190)	75	0/3	-
				1744 (253)	100	0/3	-
		E	Trans.	1110 (161)	75	3/3	61, 117, 156
				1476 (214)	100	3/3	58, 68, 125
		E	Long.	1110 (161)	75	3/3	57, 61, 61
				1469 (213)	100	3/3	45, 49, 59
Inconel 718	0.635 (0.25)	*	Trans.	862 (125)	75	0/3	-
				1145 (166)	100	0/3	-
			Long.	841 (122)	75	0/3	-
				1124 (163)	100	0/3	-
	0.033 (0.013)	*	Trans.	841 (122)	75	0/3	-
			Long.	841 (122)	75	0/3	-
Carpenter 20 Cb	7.62 (3.0) Dia. Bar	*	Trans.	248 (36)	75	0/3	-
				331 (48)	100	0/3	-
			Long.	290 (42)	75	0/3	-
				386 (56)	100	0/3	-
	0.160 (0.063)		Trans.	241 (35)	75	0/3	-
				324 (47)	100	0/3	-
			Long.	269 (39)	75	0/3	-
				365 (53)	100	0/3	-

TABLE IV (Continued)

STRESS CORROSION CRACKING OF VARIOUS HIGH STRENGTH FERROUS AND NICKEL ALLOYS

Alloy	Thickness cm (in)	Heat Treatment*	Direction of Stress	Applied Stress MN/m^2 (ksi)	Applied Stress % of Y.S.	Failure Ratio	Days to Failure
Carpenter 20 Cb-3	5.08 (2.0) Dia. Bar	*	Trans.	241 (35)	75	0/3	-
				317 (46)	100	0/3	-
			Long.	269 (39)	75	0/3	-
				352 (51)	100	0/3	-
	2.54 (1.0) Dia. Bar	*	Trans. (2) C-Rings	269 (39)	75	0/3	-
				325 (51)	100	0/3	-
	0.160 (.063)	*	Trans.	310 (45)	75	0/3	-
				407 (59)	100	0/3	-
			Long.	296 (43)	75	0/3	-
				393 (57)	100	0/3	-
L-605	2.54 (1.0) Dia. Bar	*	Long.	345 (50)	75	0/3	-
				455 (66)	100	0/3	-
			Trans. (2) C-Rings	228 (33)	50	0/3	-
				345 (50)	75	0/3	-
				455 (66)	100	0/3	-
	0.160 (.063)		Trans.	359 (52)	75	0/3	-
				476 (69)	100	0/3	-
			Long.	372 (54)	75	0/3	-
				496 (72)	100	0/3	-
Multiphase MP-35N	2.54 (1.0) Dia. Bar	*	Long.	917 (133)	50	0/3	-
				1448 (210)	75	0/3	-
				1840 (267)	100	0/3	-
			Trans. (2)	917 (133)	50	0/3	-
				1448 (210)	75	0/3	-
				1840 (267)	100	0/3	-
AISI 4130 Steel	6.35 (2.5) Dia. Bar	A	Trans.	800 (116)	75	0/3	-
				1069 (155)	100	0/3	-
			Long.	800 (116)	75	0/3	-
				1069 (154)	100	0/3	-
	0.152 (.060)	A	Trans.	738 (107)	75	0/3	-
				979 (142)	100	0/3	-
			Long.	758 (110)	75	0/3	-
				1014 (147)	100	0/3	-
	6.35(2.5) Dia. Bar	B	Trans.	834 (121)	75	0/3	-
				1110 (161)	100	0/3	-
			Long.	765 (111)	75	0/3	-
				1020 (148)	100	0/3	-
	0.152 (0.060)	B	Trans.	855 (124)	75	0/3	
				1179 (171)	100	3/3	109, 134, 144
			Long.	883 (128)	75	0/3	-
				1179 (171)	100	2/3	28, 56

* See Table III for Heat Treatments

(1) Four Specimens were Tested in Salt Spray. Only Failures were to C-Rings in Salt Spray

(2) Load Calculations Based on Longitudinal Properties

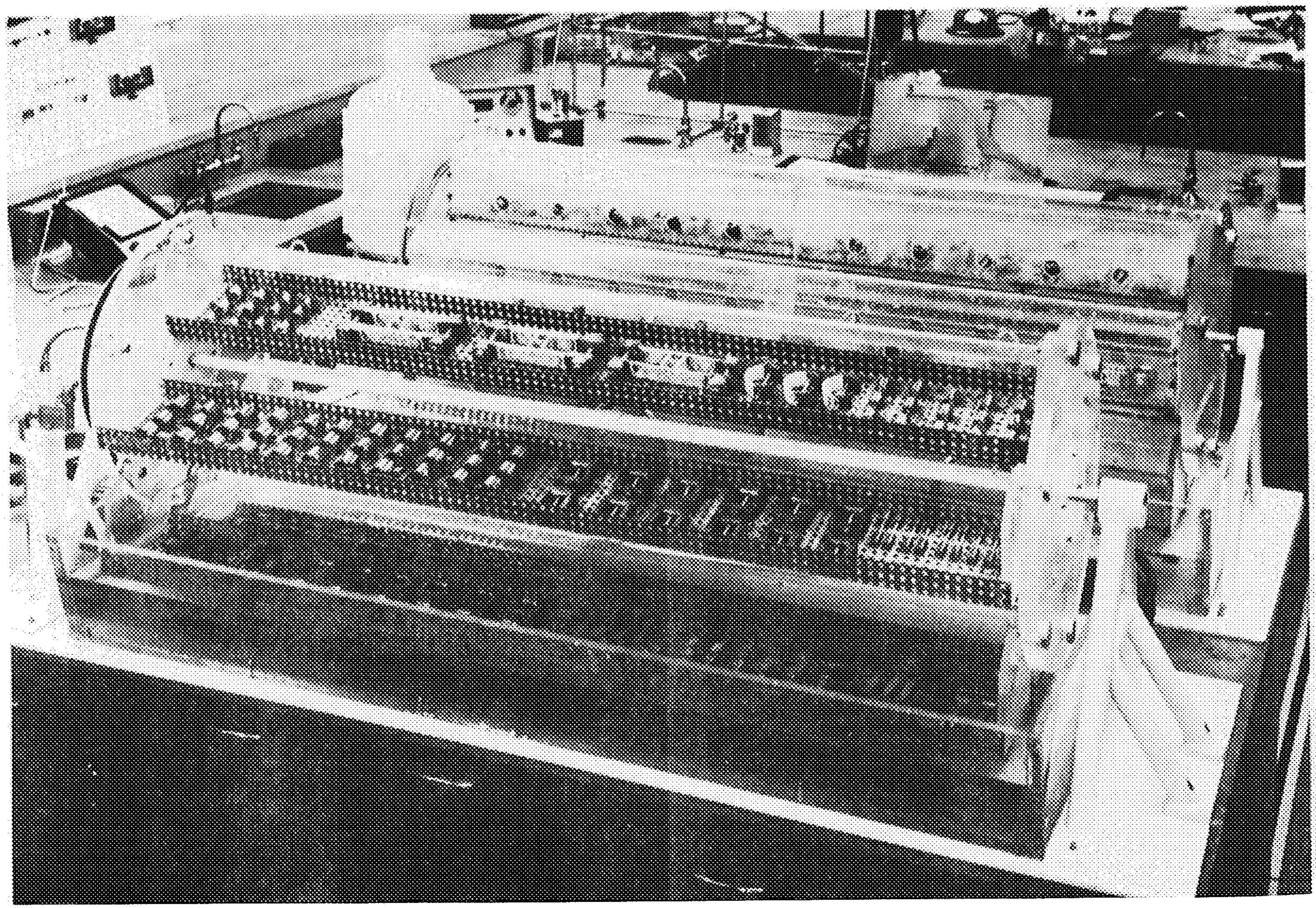
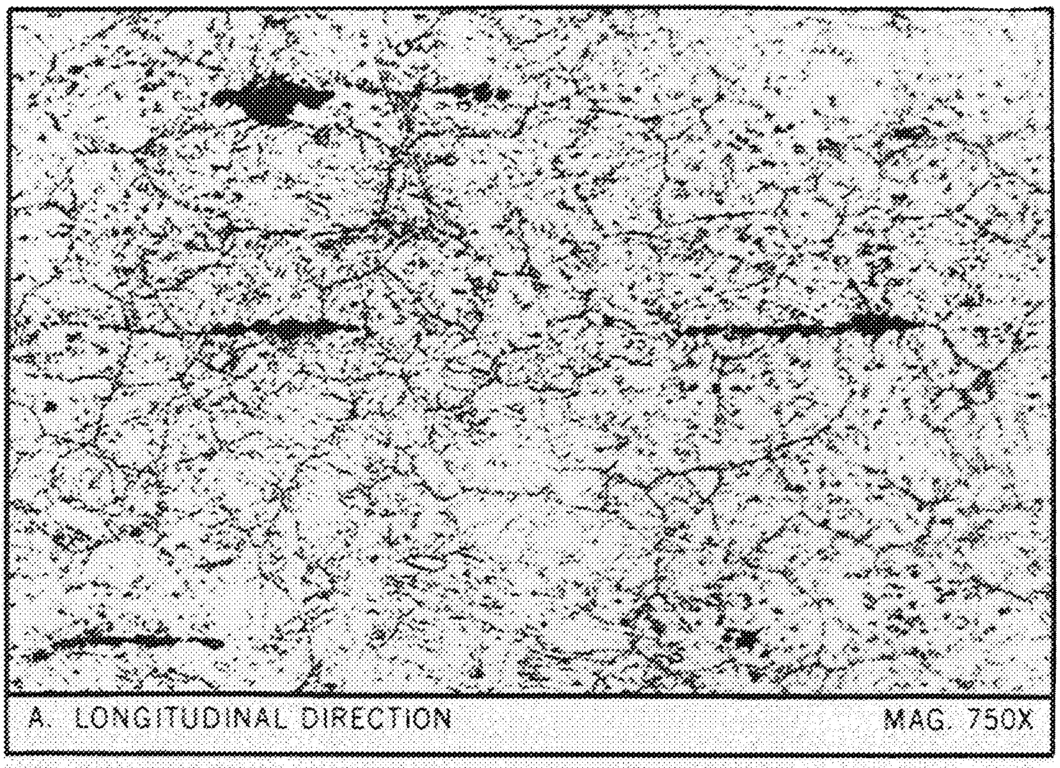


FIGURE 1 - ALTERNATE IMMERSION TESTER



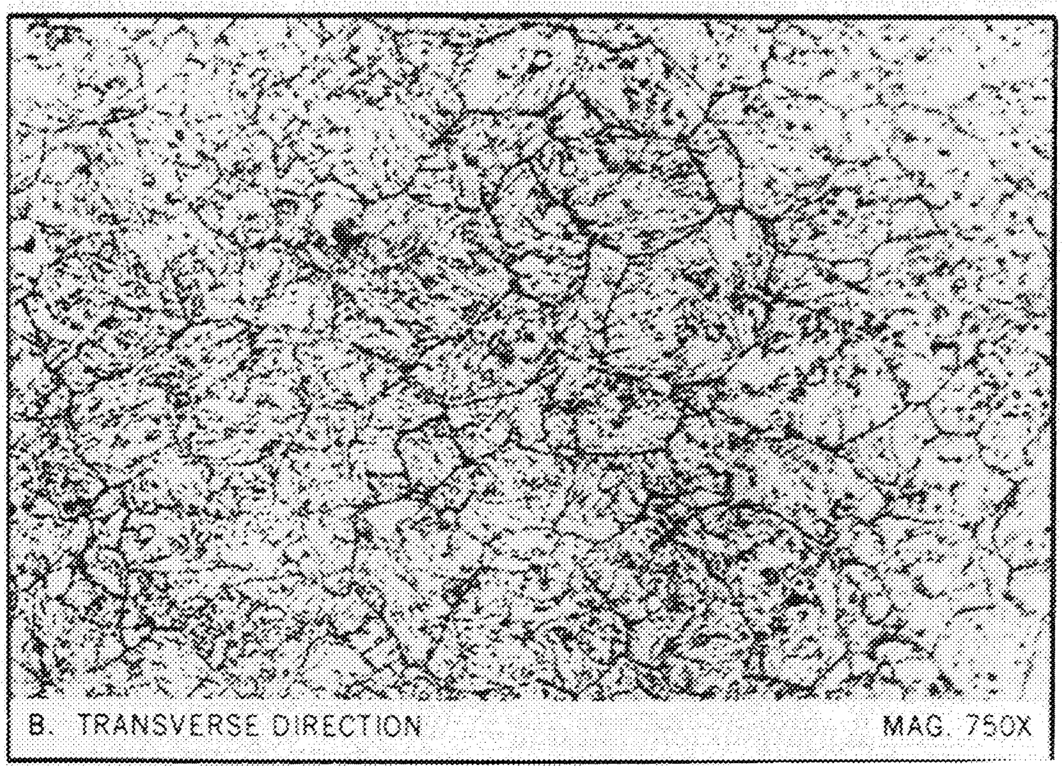


FIGURE 2 - AISI 410 STAINLESS STEEL SHOWING INCLUSIONS & SMALL GRAIN WITH CARBIDE PRECIPITATION. HEAT TREATMENT A.

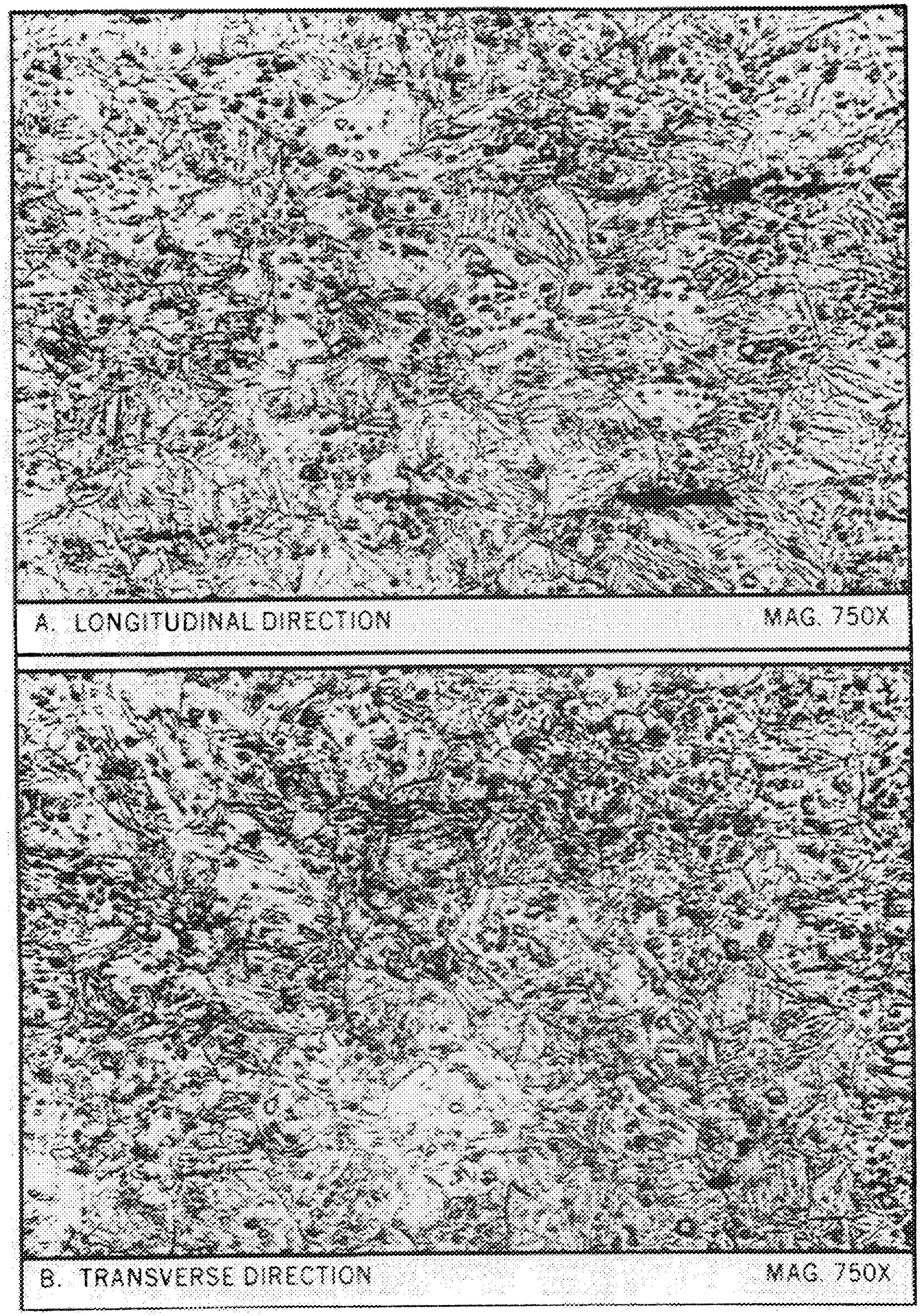
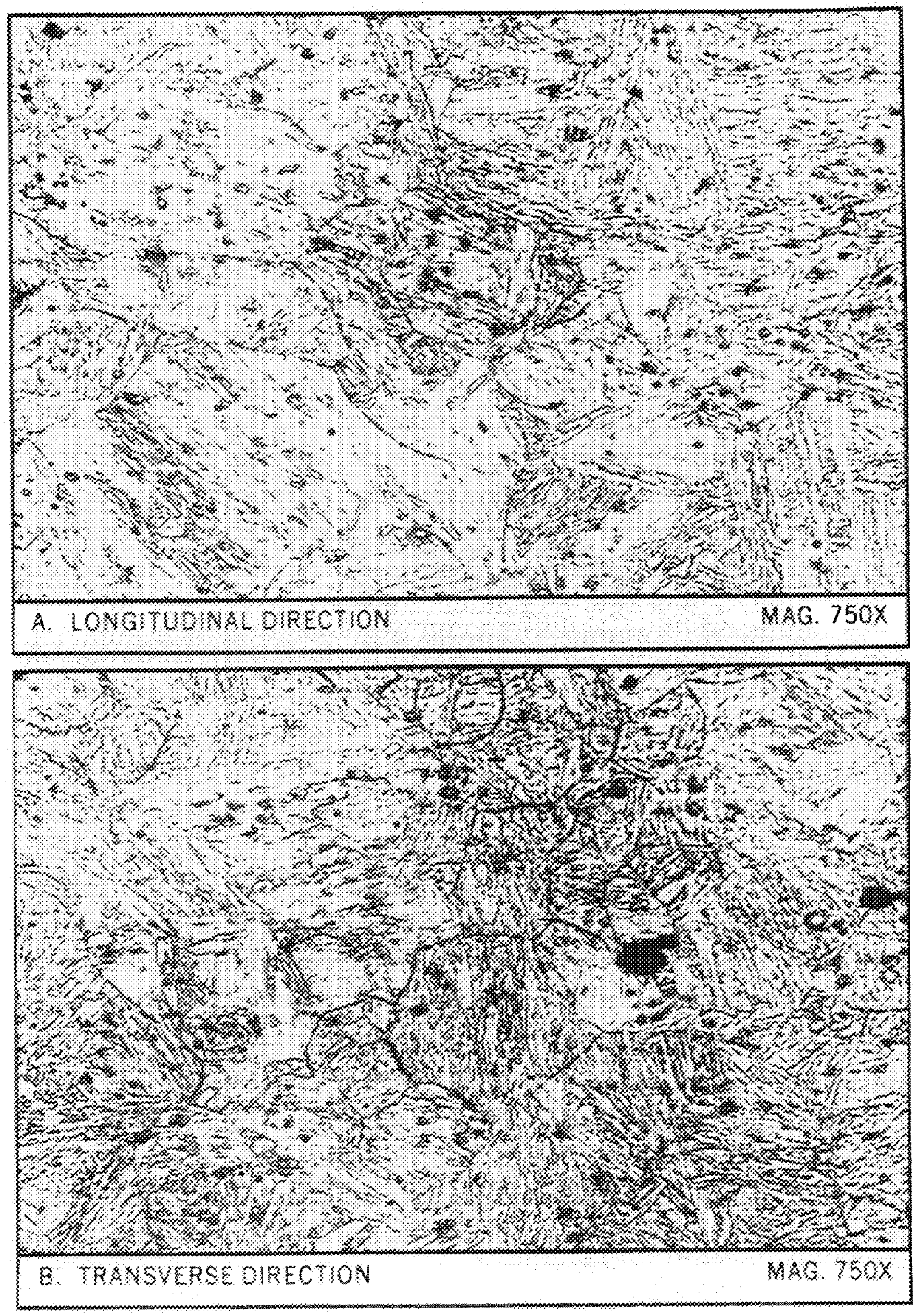


FIGURE 3 - AISI 410 STAINLESS STEEL WITH FINE GRAIN & NO CARBIDE PRECIPITATION. HEAT TREATMENT B.



A. LONGITUDINAL DIRECTION MAG. 750X

B. TRANSVERSE DIRECTION MAG. 750X

FIGURE 4 - AISI 410 STAINLESS STEEL WITH LARGE GRAIN.
HEAT TREATMENT C.

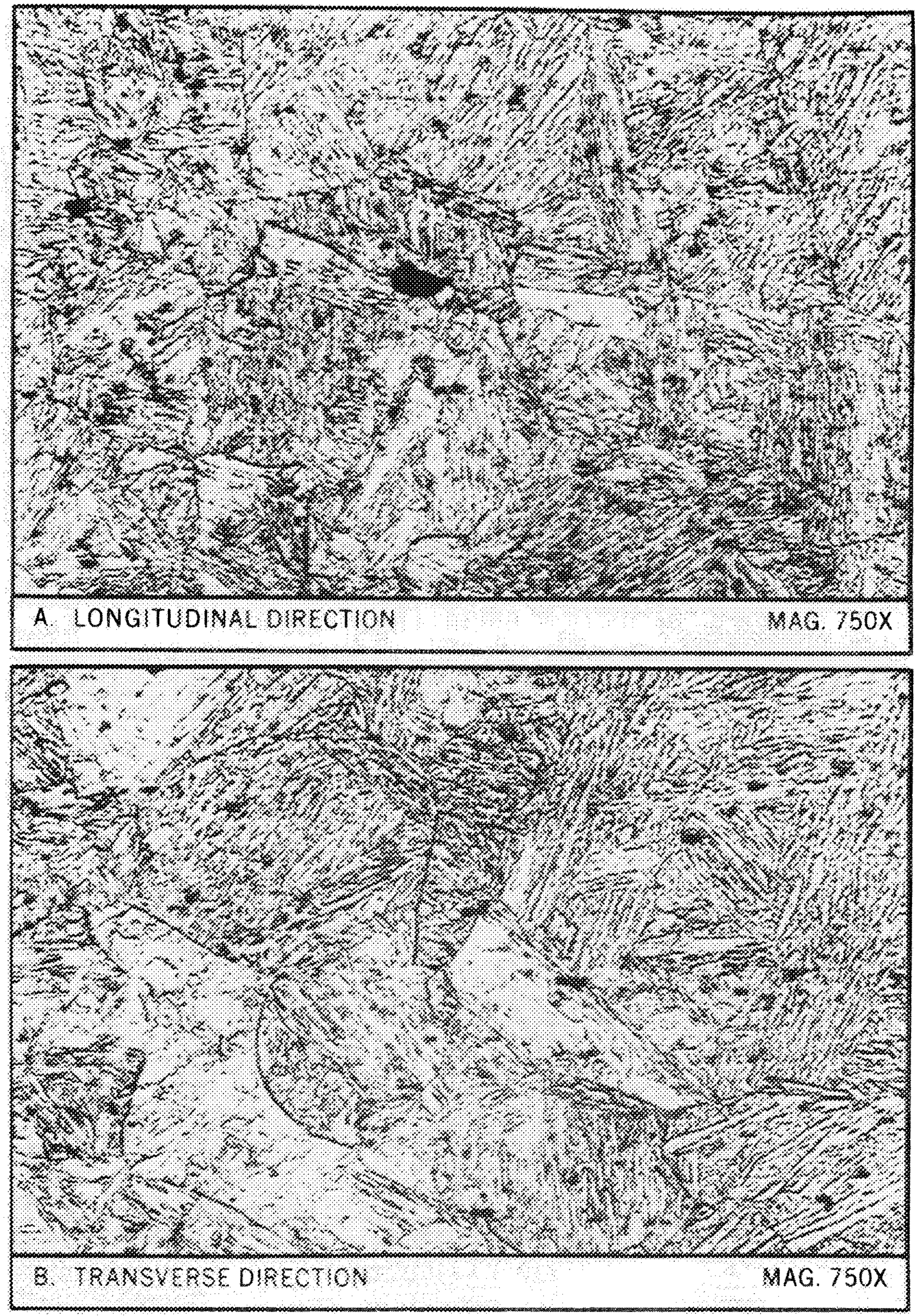
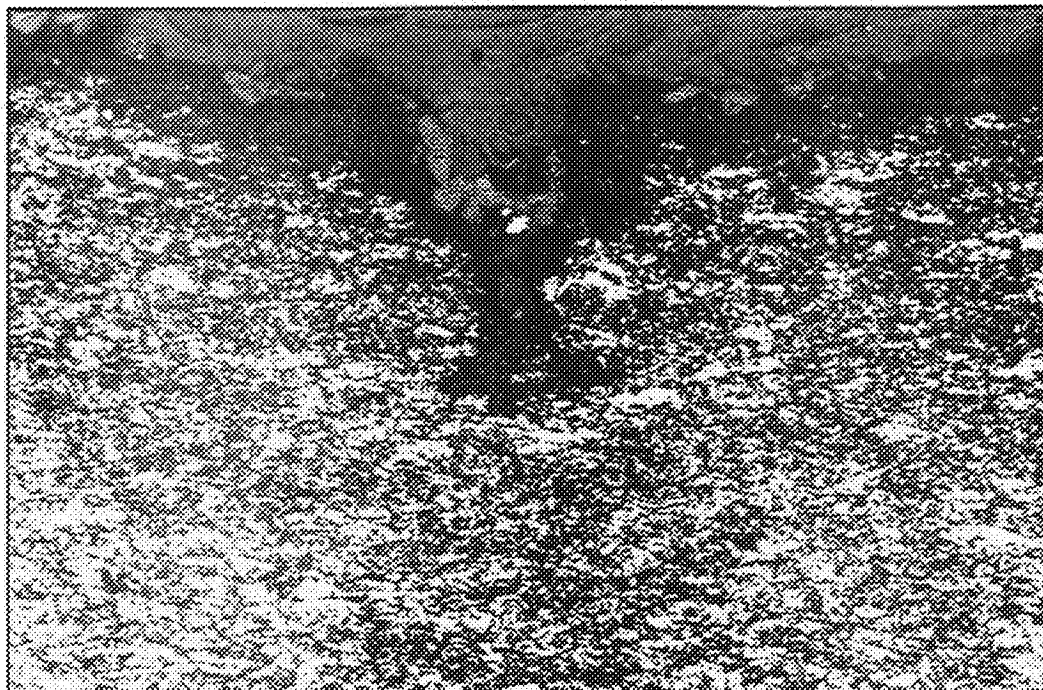
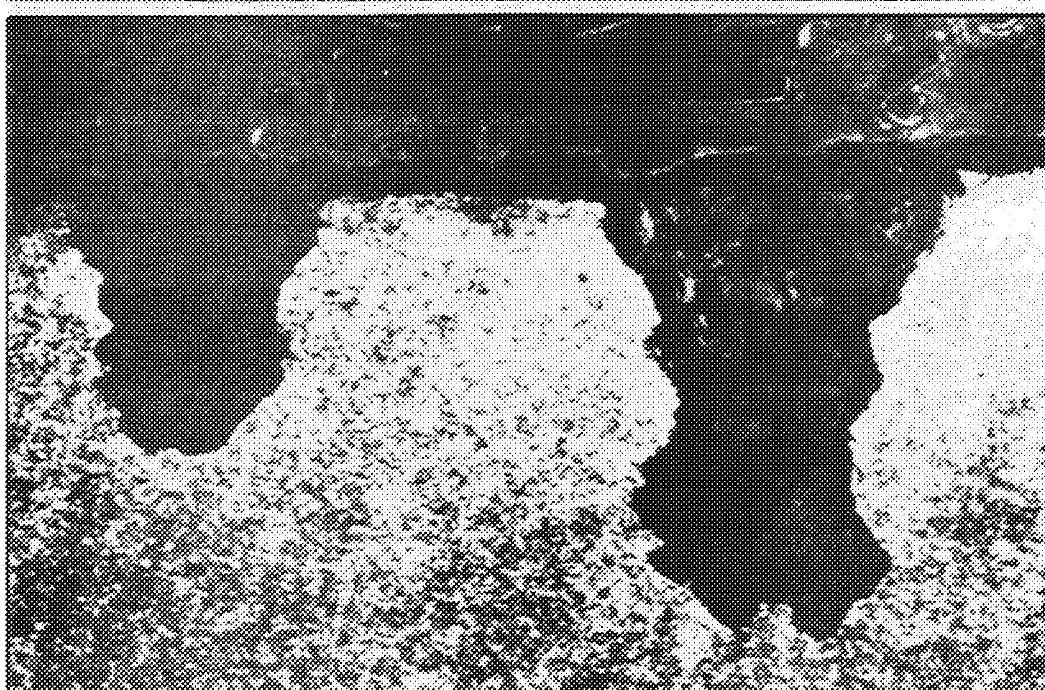


FIGURE 5 - AISI 410 STAINLESS STEEL WITH LARGE GRAIN.
HEAT TREATMENT D.

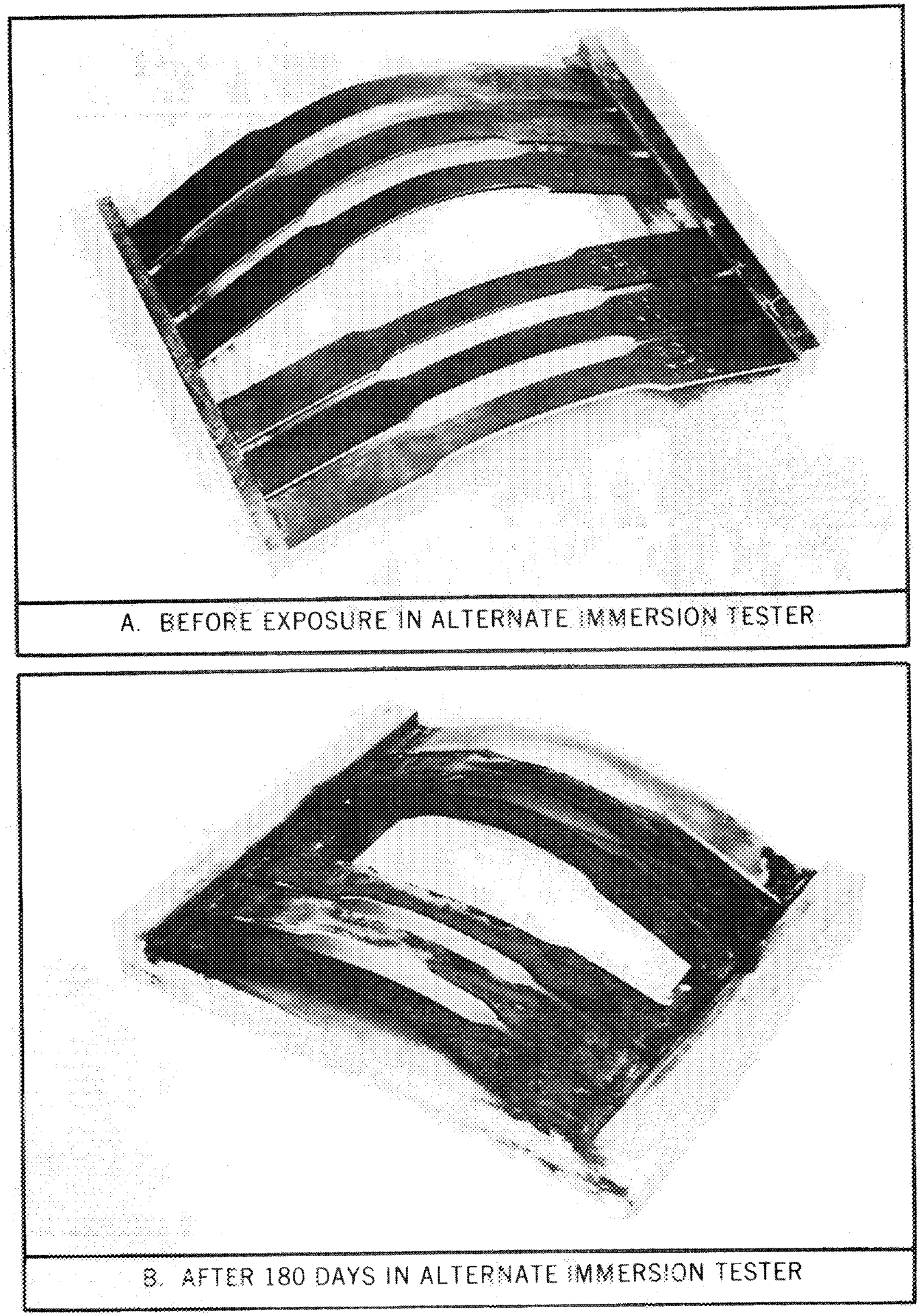


A. TRANSVERSE DIRECTION (BRIGHT FIELD ILLUMINATION) MAG. 300X



B. TRANSVERSE DIRECTION (DARK FIELD ILLUMINATION MAG. 500X

FIGURE 6 - 18 Ni MARAGING STEEL SHOWING PIT TYPE CORROSION.



A. BEFORE EXPOSURE IN ALTERNATE IMMERSION TESTER

B. AFTER 180 DAYS IN ALTERNATE IMMERSION TESTER

FIGURE 7 - STRESSED AISI 4130 STEEL SPECIMENS CADMIUM PLATED WITH CHROMATE TREATMENT.

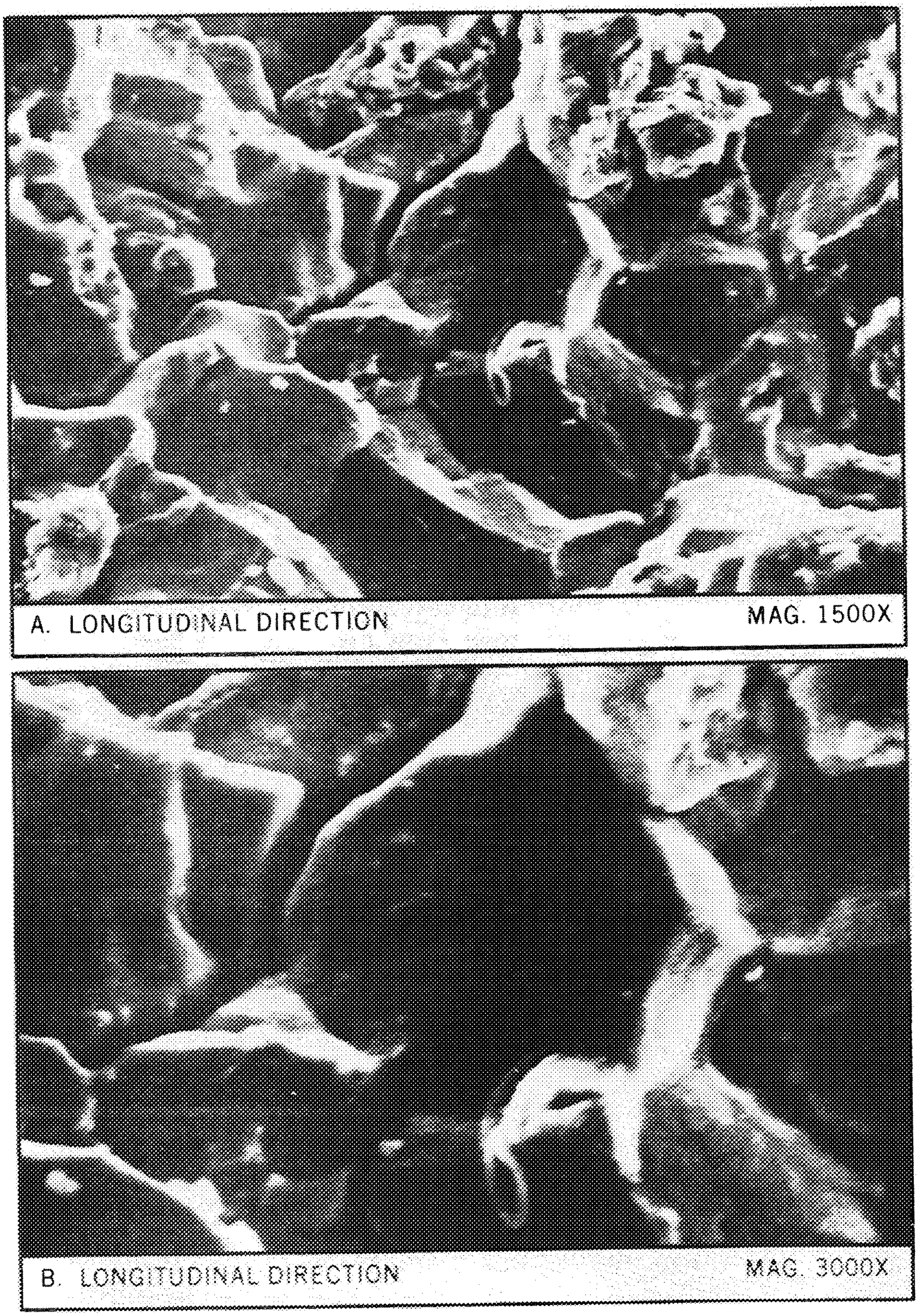


FIGURE 8 - AISI 4130 STEEL SHOWING TYPICAL STRESS CORROSION PATTERN.

APPROVAL

STRESS CORROSION CRACKING OF SEVERAL HIGH
STRENGTH FERROUS AND NICKEL ALLOYS

By

Eli E. Nelson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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